Risk Management of Box Culvert Construction Work at Bh 1149 Cross Cirebon - Kroya with Failure Mode and Effect Analysis and Fault Tree Analysis Method

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Abstract. One of the efforts made by the government in improving the quality of infrastructure is the replacement of armco to box culvert at BH 1149 between Linggapura Station - Bumiayu Station on the Cirebon - Kroya crossing. The purpose of this study is to determine the potential risks that exist during the construction process. The analysis was carried out using the Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) methods to determine the causal factors of the risk occurrence by depicting the failure tree. The results of this analysis showed that there were 67 risk variables from the construction project and obtained the 6 highest risk variables from each work group namely slings cut off in material procurement work with an RPN value of 86,838, excavator rolled over in preparation work with a value of 82,811, heavy equipment damage in railroad bridge work with an RPN value of 83,741, punctured/scratched/tripped on box culvert work with an RPN value of 70,272, slipped on track work with an RPN value of 12,938, mired in retaining wall work with an RPN value of 55,594. In handling and preventing potential work accidents, the role of contractors and workers is very influential in reducing the number of incidents. Contractors can conduct regular evaluations of risk control and workers are required to comply with existing regulations regarding Occupational Health and Safety. Thus, a safe and comfortable workplace for workers will be obtained.

Keywords: Risk Management, Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), Occupational Health and Safety (OHS), Box Culvert.

1. INTRODUCTION

In order to support smooth train travel, the Directorate General of Railways seeks to improve the quality of railway infrastructure. One of the efforts is the replacement of armco to box culvert at BH 1149 KM. 312+075 between Linggapura Station - Bumiayu Station on the Cirebon – Kroya crossing. This replacement activity was carried out due to the identification of a collapse on the upstream line.

The project of replacing armco to box culvert on BH 1149, of course, will involve a lot of labor and work equipment so that it can potentially cause work accidents. Work accident is an undesirable and accidental event related to the course of construction work that can result in loss of time, property, and life [1]. There are four main factors that cause work accidents, namely human factors, environmental factors, equipment/technical factors, and management factors [2]. According to BPJS Employment data in 2023, the number of work accidents in 2020 reached 221,740 cases. This number increased to 234,370 cases in 2021 and 265,334 cases until November 2022. The construction sector alone accounts for 32% of the total work

A. Pradipta et al. (eds.), *Proceedings of the 2nd International Conference on Railway and Transportation 2023 (ICORT 2023)*, Advances in Engineering Research 231,
https://doi.org/10.2991/978-94-6463-384-9_13

accidents in Indonesia each year [3]. This proves that in Indonesia the level of work accidents in the construction services sector is still high.

Thus, an OHS (Occupational Safety and Health) risk management system must be implemented because there is no denying that accidents will occur during the construction implementation process. The role of OHS risk management is to ensure that every worker is protected for their health and safety so that the risk due to work accidents during the construction process can be minimized [4]. The risk management system is expected to create a safe, comfortable, efficient, and productive work site [5].

The risk in the BH 1149 construction project is considered to have a fairly high level because the path on BH 1149 is an active path with high traffic so that it has a risk that can endanger workers if not equipped with the right PPE and standard operating procedure. For this reason, it is necessary to conduct a review related to the application of risk management in this project.

Work accident is an unwanted and unexpected event that can result in injury, property damage, and loss of life [6]. Work accidents are also said to have a relationship with activities that occur due to work while doing work or while traveling to or from work [7]. According to Sucipto (2014), the causes of work accidents are divided into 2, namely immediate causes consisting of unsafe acts and unsafe conditions. The basic cause is a cause consisting of human factors and work and environmental factors.

Risk control is carried out in order to reduce the impact of risks posed to workers during work [9]. In determining how to handle and prevent work accidents, it must be considered thoroughly [10]. Risk control is carried out based on the results of hazard identification and prioritization and the control to be carried out is determined based on the results of the risk ranking. If a risk of occupational accidents and occupational diseases has been identified and evaluated, risk control must be used to reduce the risk to an acceptable limit by applicable regulations and standards.

Failure Mode and Effect Analysis (FMEA) is a systematic approach that applies labeling by identifying failure modes, causes of failure, and effects of failure. In this method, it will be classified based on the level of potential failure and the effects given [11]. FMEA is a technique for assessing the reliability of a system to determine the effects of system failures based on severity, occurrence, and detection. The purpose of using the Failure Mode and Effect Analysis (FMEA) method in conducting the analysis is: [12]

1. Identify and understand potential failure modes and their causes for specific product processes, and the impact of failure on the system.
2. Assess the risks associated with identified failure modes, effects and causes and prioritize issues for corrective action.
3. Identify and implement corrective actions to address the most serious problems.

Fault Tree Analysis (FTA) is a method used to identify failures that occur [13]. FTA is a tool for analyzing, visualizing (drawing) and evaluating the failure path of a system, providing a mechanism for assessing the danger level of the system [14]. FTA shows the relationship that occurs between causal factors and the output displayed in the form of a fault tree starting from the top event to the basic event and connected using logic gates in the form of "and" gates and "or" gates. If an "and" relationship occurs, then the event that occurs above it will occur if the two events below it occur.

Unlike the "and" relationship, the "or" relationship means that an event will occur if one of the events below it occurs.

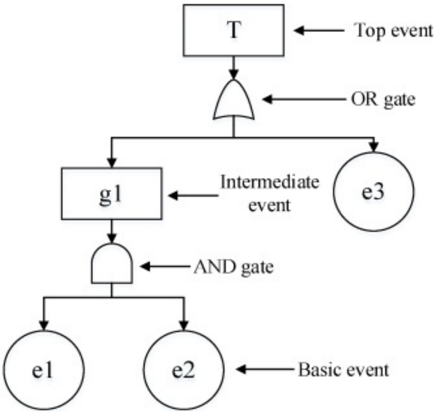

Figure 1. Fault Tree Analysis
Source: [15]

2. METHODOLOGY

2.1 Data Collection

The data collection method is carried out in order to collect the data and information needed to complete the research. Data collection is done by conducting field surveys, questionnaires, interviews, and project documents.

2.2. Population and Sample

In this study there are two methods used in selecting samples, namely purposive sampling and saturated samples. Purposive sampling was used to fill out a preliminary questionnaire aimed at implementing contractors, consultants and occupational health and safety officers. The preliminary questionnaire was used to identify potential risks in the construction project. For filling out the main questionnaire, the saturated sample method was used, namely using the entire population because the population was less than 30 people [16]. This main questionnaire will later be used as a risk assessment.

2.3 Data Analysis

From the data that has been collected, it will then be analyzed to find work items that have the greatest potential risk from each job. Measurement of the level of risk value is carried out using the formula:

$$RPN = S \times O \times D \quad (1)$$

Desciption:

RPN = Risk Priority Number
S = Severity
O = Occurance
D = Detection

3. RESULT AND DISCUSSION

3.1 Identification of Potential Risks

From the results of the analysis that has been carried out, 67 risk variables were found which will then be calculated the risk rating using Equation 1. From the calculation results, the 6 highest potential risks of each job are obtained as follows:

Table 1. Potential Risk Variables

No	Type of Work	Potential Risks	RPN Value
1	Material Procurement	Wire rope was broken and fell on a worker while unloading material from the hauler	86.838
2	Preparatory Work	Excavator rolled over during access road construction	82.811
3	Railway Bridge Work	Damage to heavy equipment when lifting IWF 700	83.741
4	Box Culvert Work	Punctured / scratched / tripped during the process of fixing the box culvert	70.272
5	Track Work	Slipped when lifting the existing electrical wires R54	12.938
6	Retaining Wall Work	Falling into the excavation during excavation work	55.594

3.2 Identification of Causal Factors

After finding the highest risk variables, it will continue to analyze the causes of accidents using the Fault Tree Analysis (FTA) method. This method is carried out with a top down approach, namely by starting with the assumption of a fault described as a top event to a basic event. The purpose of using this method is to find the cause of failure so as to minimize the occurrence of failure.

3.3. Drawing of Fault Tree Analysis (FTA)

After knowing the factors that cause work accidents that have been divided into intermediate events and basic events, the next step is to draw a failure tree connected by an "and gate" or "or gate" logic gate. Steps in using the Fault Tree Analysis (FTA) method:

1. Identify the most important event or incident in the system (top event).
2. Creating a fault tree (Fault Tree Analysis)
3. Analyzing the fault tree
   a) Determining the minimum cut set:
   b) Identify "and" and "or"
   c) b) Naming each event

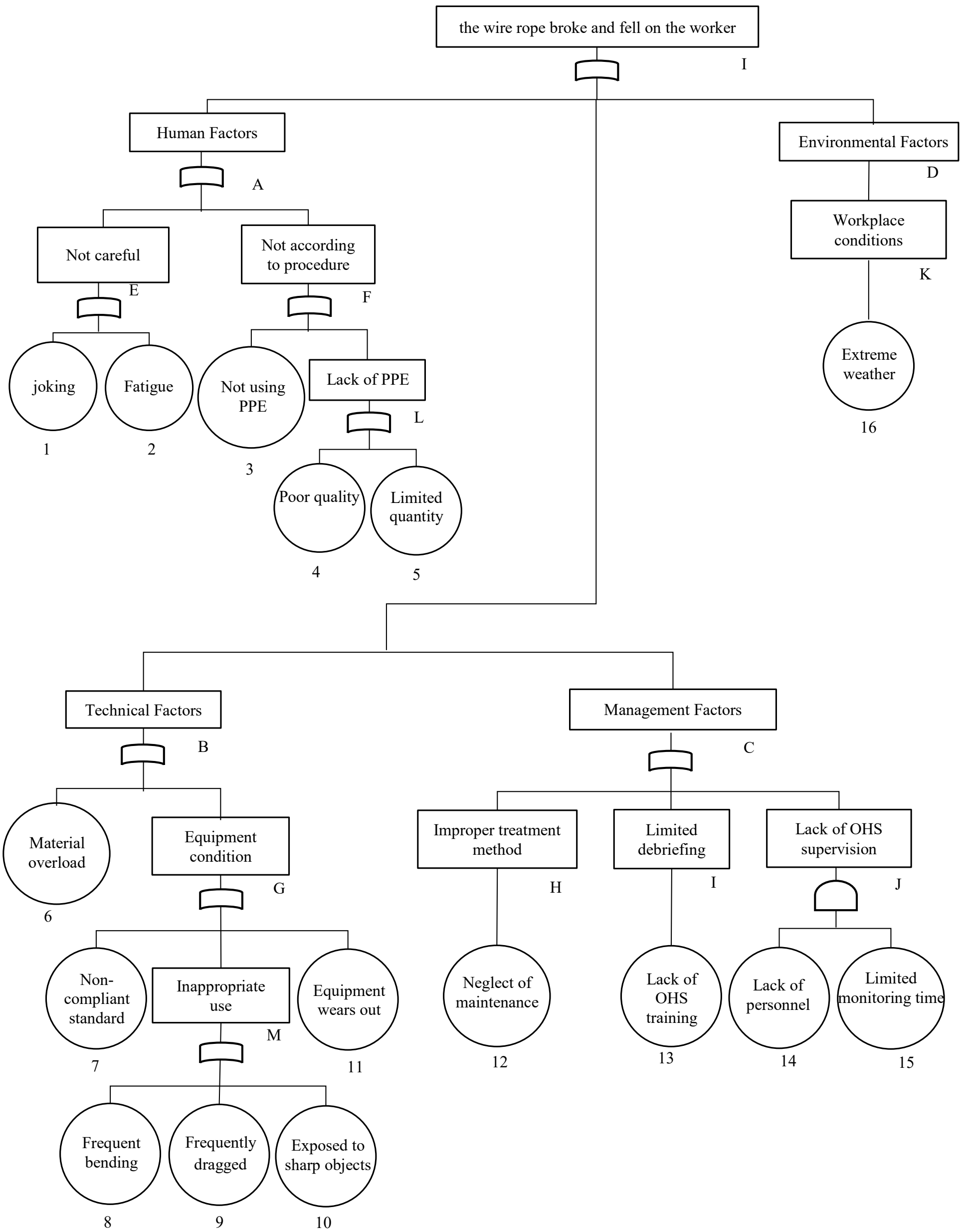

Figure 2. Fault Tree Analysis Part 1

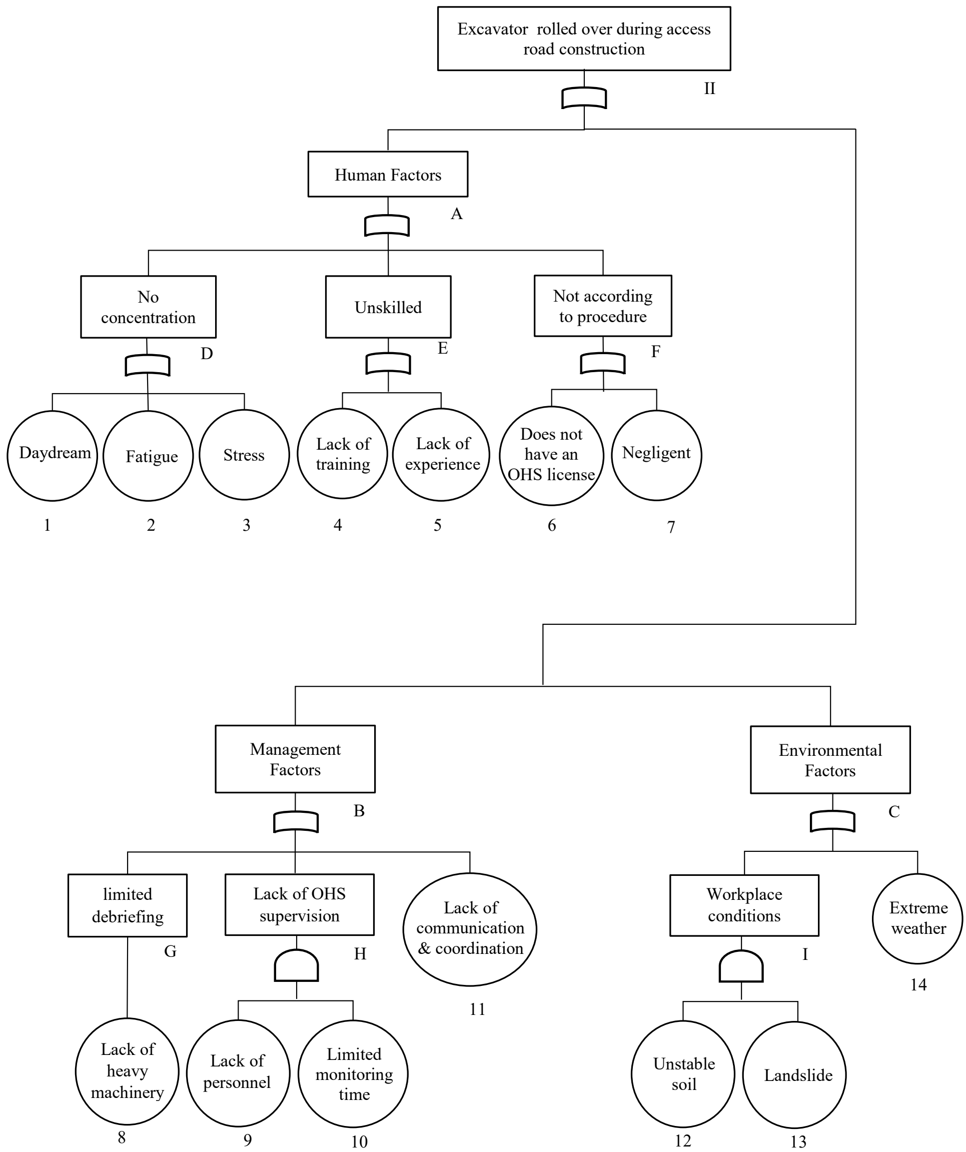

Figure 3. Fault Tree Analysis Part 2

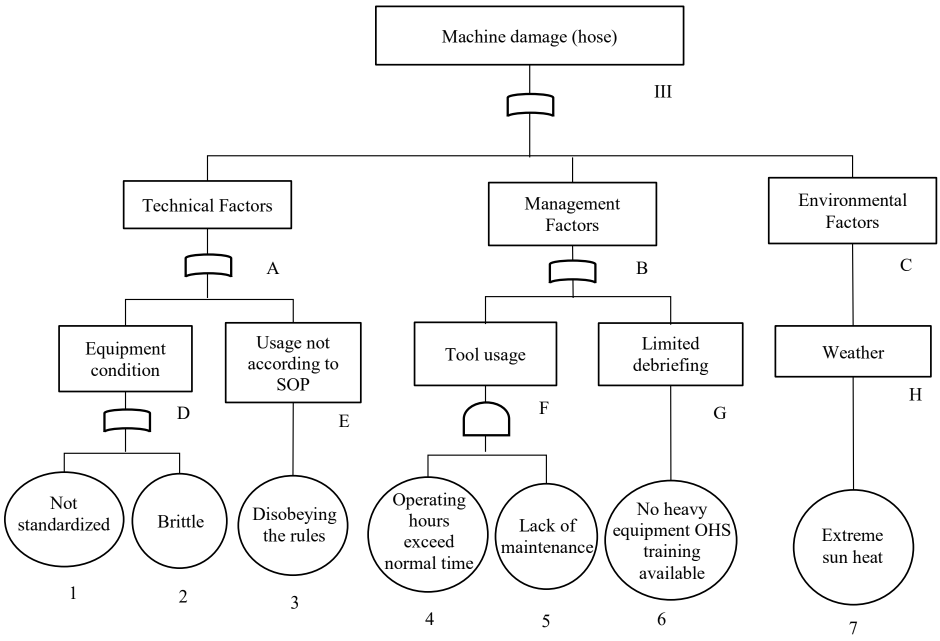

Figure 4. Fault Tree Analysis Part 3

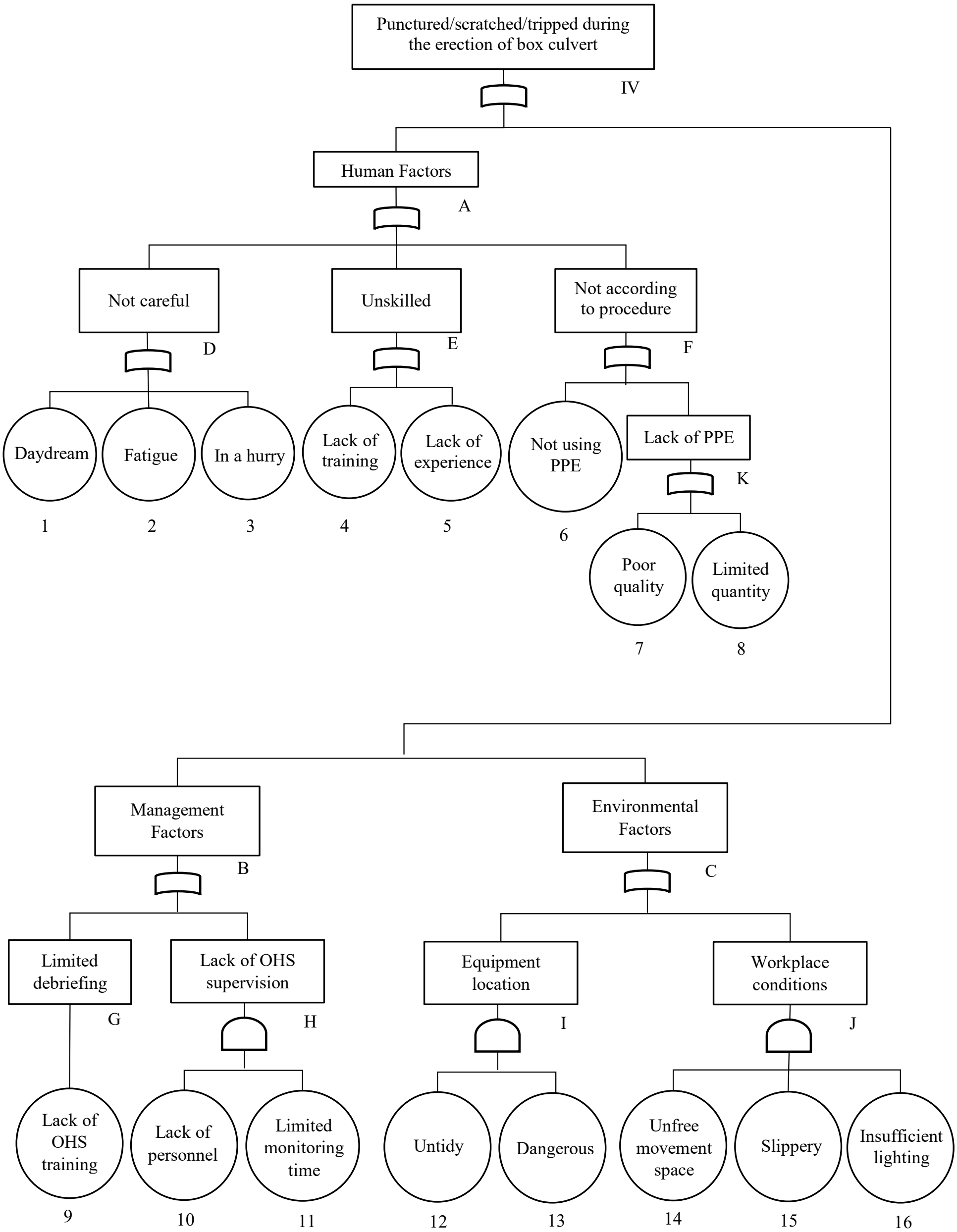

Figure 5. Fault Tree Analysis Part 4

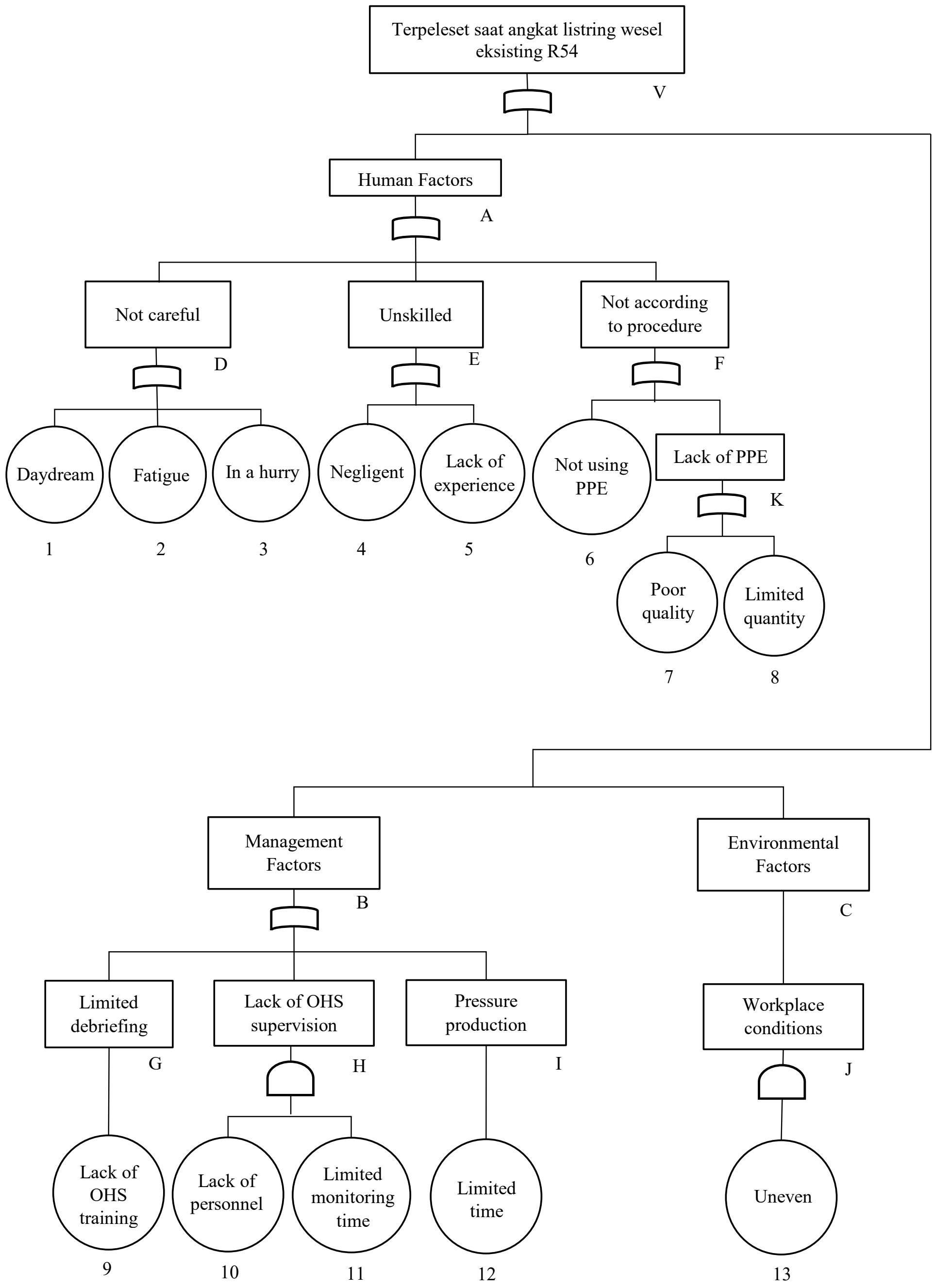

Figure 6. Fault Tree Analysis Part 5

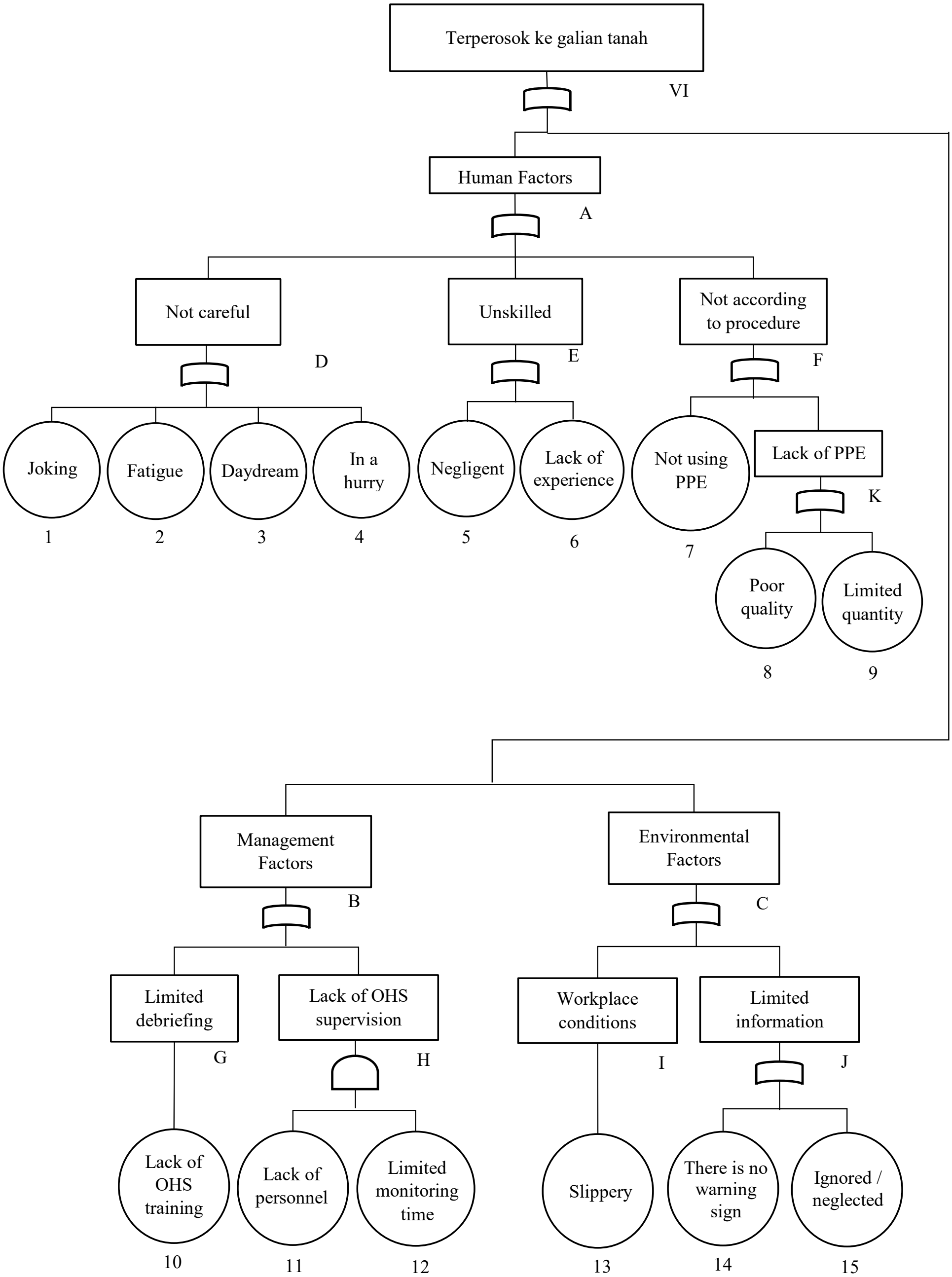

Figure 7. Fault Tree Analysis Part 6

3.4. Basic Event Combination

After drawing the Fault Tree Analysis diagram, the next step is to analyze with a minimum cut set or mocus. A cut set is a combination formed by a fault tree that if all occur will result in a top event. This minimal cut set is the smallest combination of events that results in an undesirable event, and mocus is a cut set search method. The basic event combination is obtained from the depiction of the failure tree and analyzed with the and gate or or gate relationship. The mocus analysis of each top event:

a. Mocus analysis for wire rope breakage in material procurement work

Table 2. Mocus for Wire Rope Breakage

Minimal cut set		
1	6	11
2	7	12
3	8	13
4	9	14,15
5	10	16

From the results of the fault tree depiction on the disconnected sling failure mode, 16 basic events were generated, while the minimum cut set analysis obtained 15 basic event combinations.

b. Mocus analysis for excavator rolled over in preparation work

Table 3. Mocus for Excavator Rolled Over

Minimal cut set		
1	5	9,10
2	6	11
3	7	12,13
4	8	14

From the results of the fault tree depiction on the excavator rollover failure mode, it produces 14 basic events, while in the minimum cut set analysis, 12 basic event combinations are obtained.

c. Mocus analysis for heavy equipment (hose) damage at railway bridge works

Table 4. Mocus for Heavy Equipment Damage

Minimal cut set		
1	3	6
2	4,5	7

From the results of the fault tree depiction on the failure mode of heavy equipment damage (hose) produces 7 basic events, while the minimum cut set analysis produces 6 basic event combinations.

d. Mocus analysis for puncturing/scratching/tripping on box culvert work

Table 5. Mocus for puncturing/scratching/tripping

Minimal cut set		
1	5	9
2	6	10,11
3	7	12,13
4	8	14,15,16

From the results of the fault tree depiction on the punctured / scratched / tripped failure mode, it produces 16 basic events, while the minimum cut set analysis produces 12 basic event combinations.

e. Analysis of mocus for slipping on track work

Table 6. Mocus for Slipping

Minimal cut set		
1	5	9
2	6	10,11
3	7	12
4	8	13

From the results of the fault tree depiction on the slipping failure mode, it produces 13 basic events, while the minimum cut set analysis produces 12 basic event combinations.

f. Mocus analysis for mired in retaining wall work

Table 7. Mocus for Mired

Minimal cut set		
1	6	11,12
2	7	13
3	8	14
4	9	15
5	10	

From the results of the fault tree depiction on the mired failure mode, it produces 15 basic events, while the minimum cut set analysis produces 14 basic event combinations.

3.5. Risk Mitigation Recommended

Recommended Risk Mitigation in preparing risk mitigation, researchers conducted interviews with OHS experts as well as literature studies related to these risk variables. Risk mitigation will be grouped based on the factors that cause work accidents. Handling and prevention that can be done, as follows:

Table 8. Risk Mitigatin Recomendation

No	Risk	Risk Mitigation
1.	Wire Rope was broken and fell on a worker while unloading material from the haulage equipment.	1. Increase the amount of PPE in accordance with applicable standards and quality. 2. Penalize workers who do not want to wear PPE in the form of wage deductions. 3. Inspect the slings regularly to ensure the condition of the wire rope. 4. Pay attention to where the slings are stored. Keep away from damp places, exposure to direct sunlight, and rainwater. 5. Perform maintenance on wire rope by lubricating regularly
2.	Excavator rolled over during	1. Ensure the heavy equipment operator's occupational health and safety license for lifting & transporting equipment is still valid.

No	Risk	Risk Mitigation
	access road construction	2. Conduct site surveys to review ground conditions 3. Maintain communication and coordination between surveyors and excavator operators
3.	Damage to heavy equipment (hose) when lifting IWF 700	1. Periodic inspection of heavy equipment to ensure the condition of the equipment (especially hose) is in good condition and not brittle. 2. Ensure that hose quality is in accordance with applicable standards 3. Perform maintenance on the hose periodically 4. Installing a spiral guard on the hose to protect the hose from sun exposure 5. Pay attention to the excavator operating time so as not to exceed the normal time so as not to interfere with maintenance time.
4.	Punctured/ scratched/ tripped during the process of fixing the box culvert	1. Conduct toolbox meetings every day before starting work 2. Ensure workers' understanding of work methods and instructions before starting work. 3. Pay attention to the placement and tidiness of tools and materials so as not to endanger workers. 4. Adding OHS officers so that supervision in the work can run well.
5.	Slipped when lifting the existing electrical switch R54	1. Conduct a toolbox meeting every day before starting work 2. Ensure workers' understanding of work methods and instructions before starting work. 3. Always coordinate with the train watcher
6.	Falling into the excavation during excavation work	1. Install and ensure the safe boundary of the work area using a safety line. 2. Install warning signs that there is excavation work. 3. Ensure that workers do not work too close to the excavation pit.

4. CONCLUSION

Based on the results of the analysis of potential accidents in the box culvert construction project at BH 1149, it can be concluded as follows:

1. There are 6 potential work accidents with the highest risk in each project work ranked using the FMEA method, namely slings cut off in material procurement

work with an RPN value of 86,838, excavator rolled over in preparation work with a value of 82,811, heavy equipment damage in railroad bridge work with an RPN value of 83,741, punctured/scratched/tripped on box culvert work with an RPN value of 70,272, slipped on track work with an RPN value of 12,938, mired in retaining wall work with an RPN value of 55,594.

2. The causes of the risk of work accidents in the construction of the BH 1149 box culvert based on the FTA method, which consists of human factors, technical factors, management factors, and environmental factors.
3. In handling and preventing potential work accidents, the role of contractors and workers is very influential in reducing the number of incidents. Contractors can conduct regular evaluations of risk control and workers are required to comply with existing regulations regarding Occupational Health and Safety. Thus, a safe and comfortable workplace for workers will be obtained.

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